

# Uncertainties in Climate Model Projections of Future Arctic Sea Ice Loss

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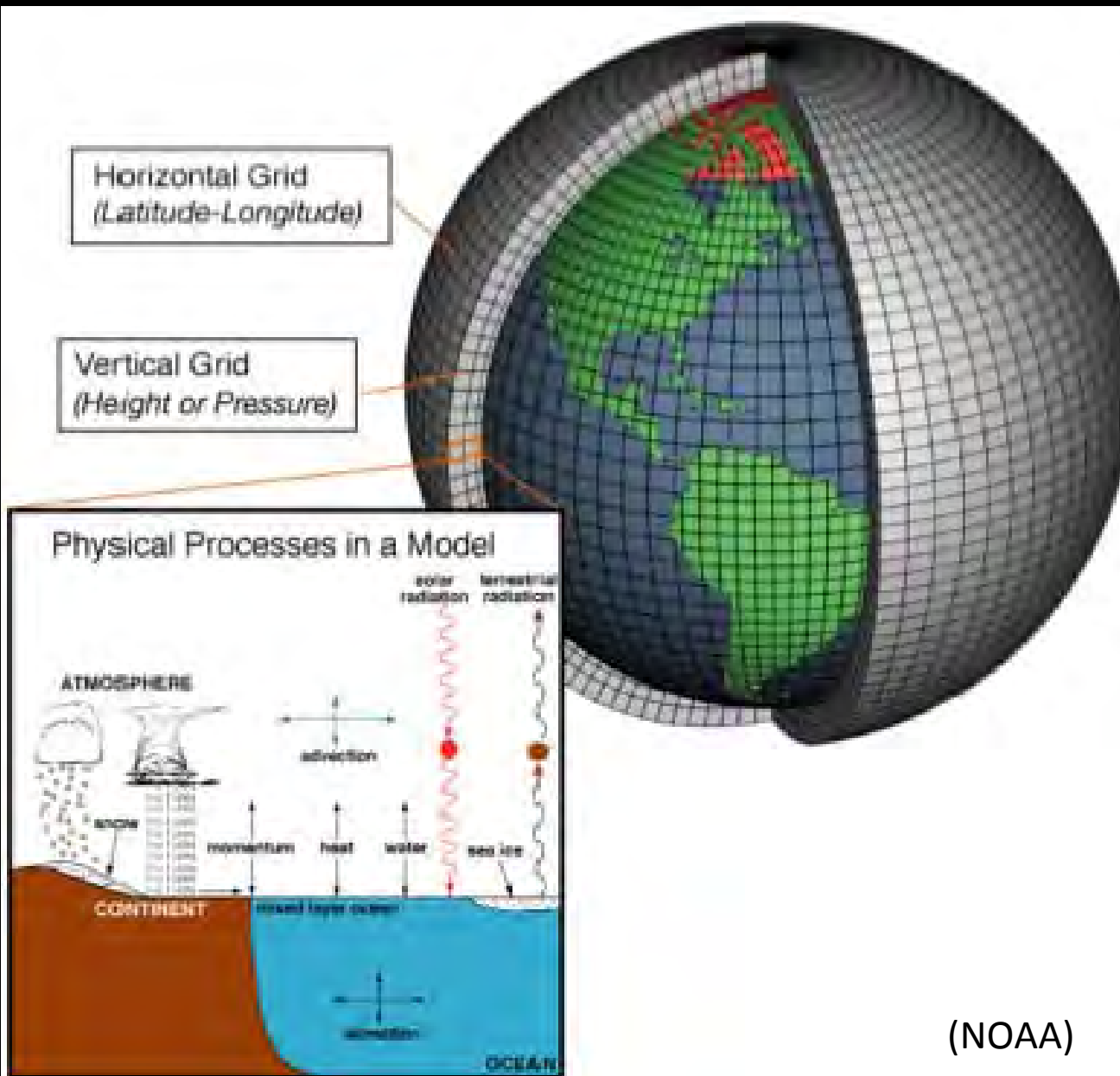
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## **CLIMATE MODEL UNCERTAINTIES IN PROJECTING FUTURE ARCTIC SEA ICE LOSS**

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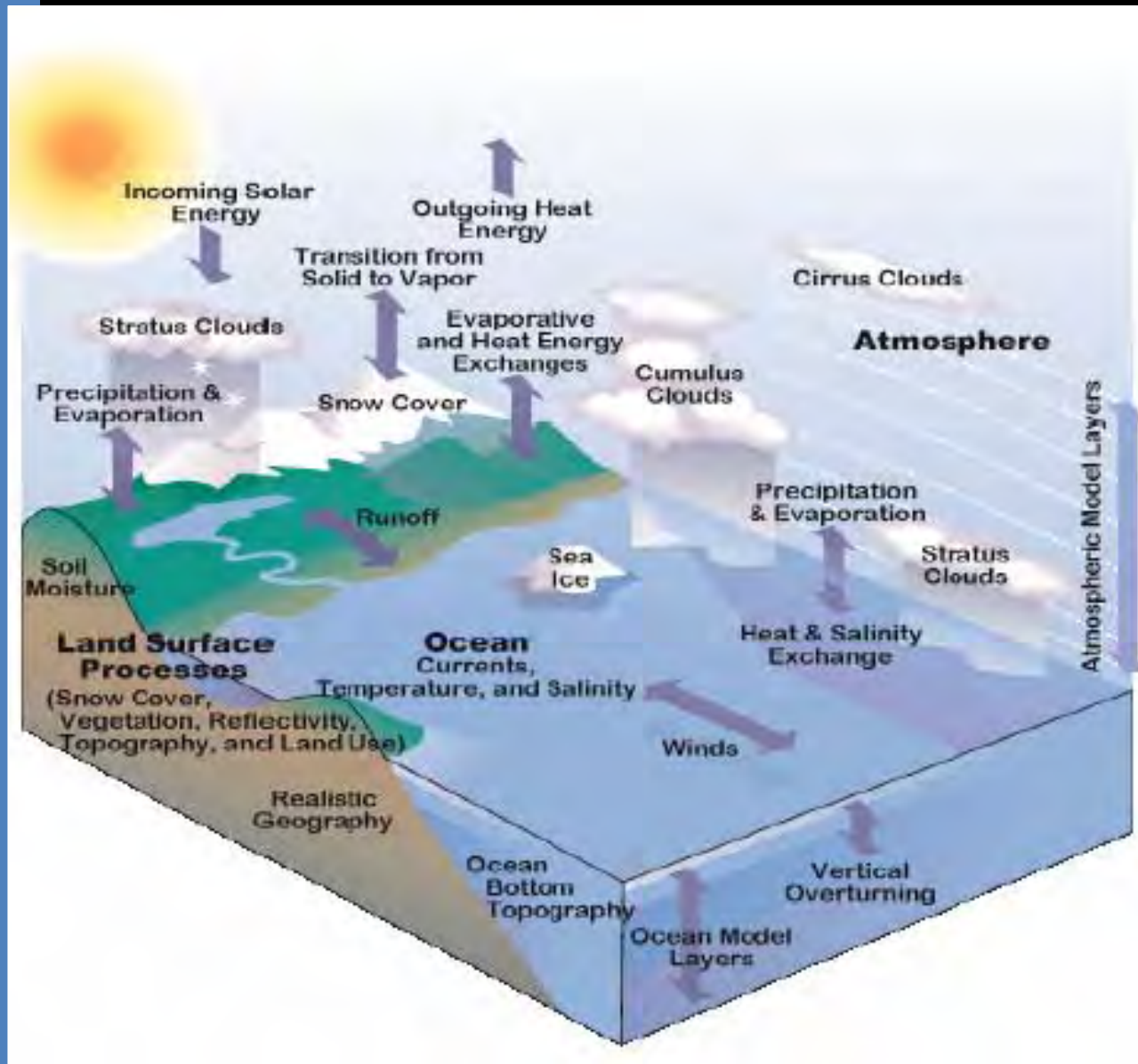
# Climate model systems



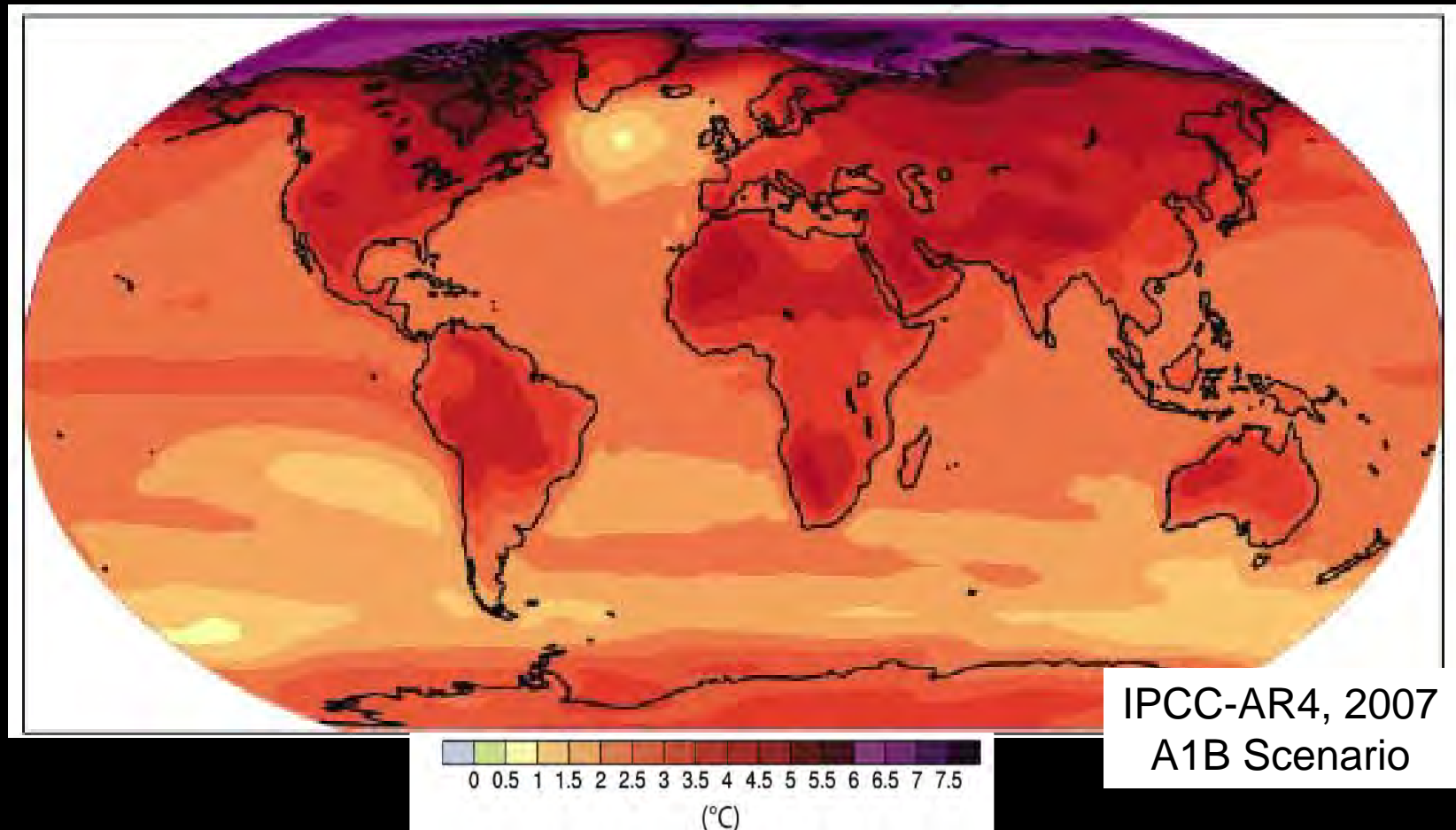
- Systems of differential equations that describe fluid motion, heat transfer, etc.
- Planet divided into 3-dimensional grid and equations solved on that grid
- Sub-gridscale processes need to be parameterized

# Coupled Climate Models

- Includes ocean, atmosphere, land, sea ice components
- Conservative exchange of heat, water, momentum across components
- Can apply changes in external forcing; solar input, GHG levels, volcanic eruptions
- Provide a “virtual laboratory” for experimentation



In response to rising greenhouse gases models project continued surface warming



Projected Air Temperature change by 2100

Global warms  $\sim 2.8^{\circ}\text{C}$ , Land warms  $\sim 3.5^{\circ}\text{C}$ , Arctic warms  $\sim 7^{\circ}\text{C}$

2080-2099 minus 1980-1999

Normalized SAT Change

Latitude

Arctic Amplification

IPCC-AR4 Models  
SRES-A1B

Zonally Avg Air  
Temp Change

Legend:

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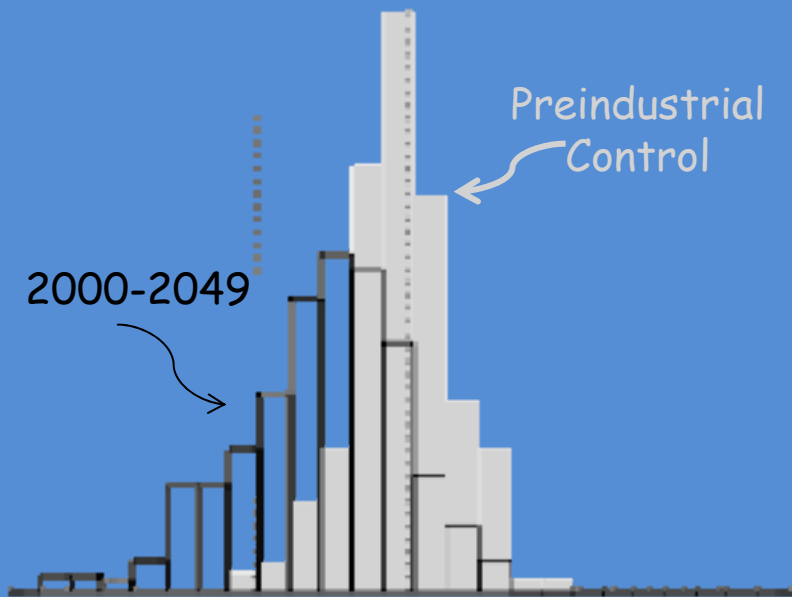
(After Holland and Bitz, 2003)

# Sources of Uncertainty in Projections of Future Climate Change

- Intrinsic climate variability

Climate models simulate the statistics of climate, not the events of any particular year

Sept Extent Decadal Trends 2000-2049



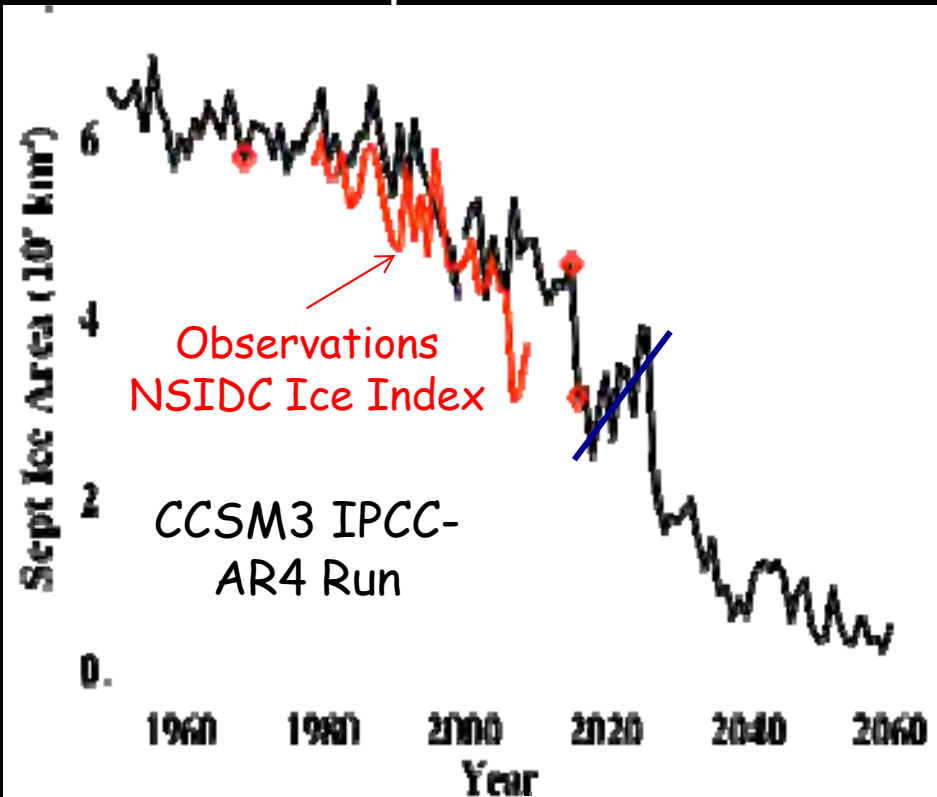
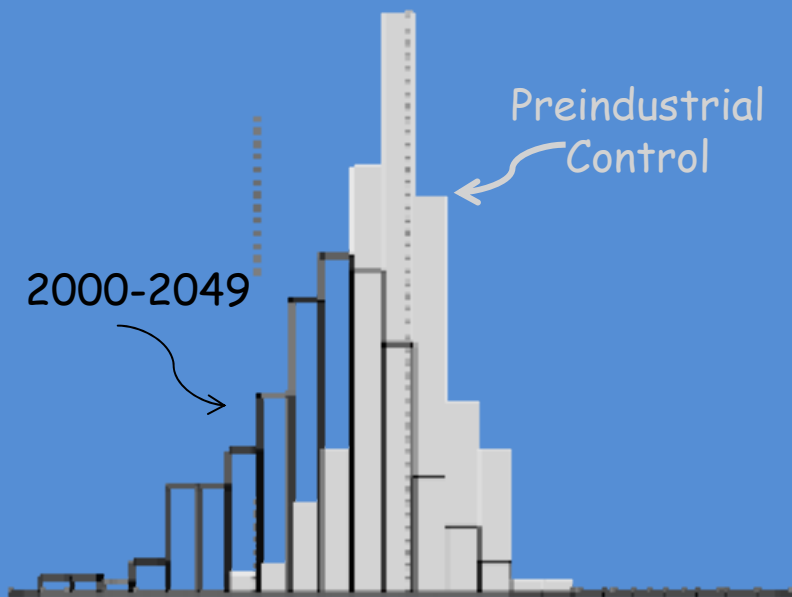
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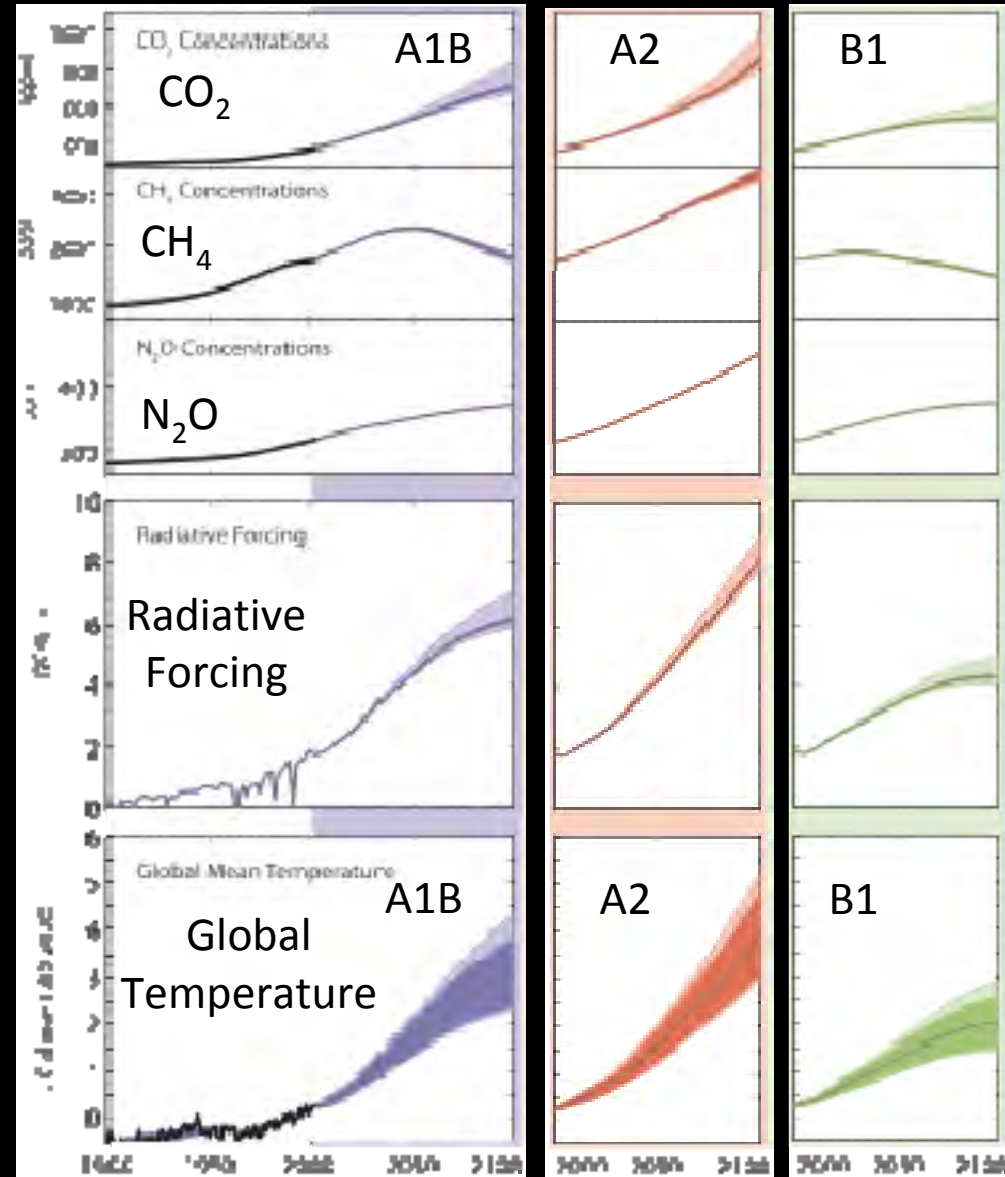
Simulated September Ice Extent

Sept Extent Decadal Trends 2000-2049



# Sources of Uncertainty in Projections of Future Climate Change

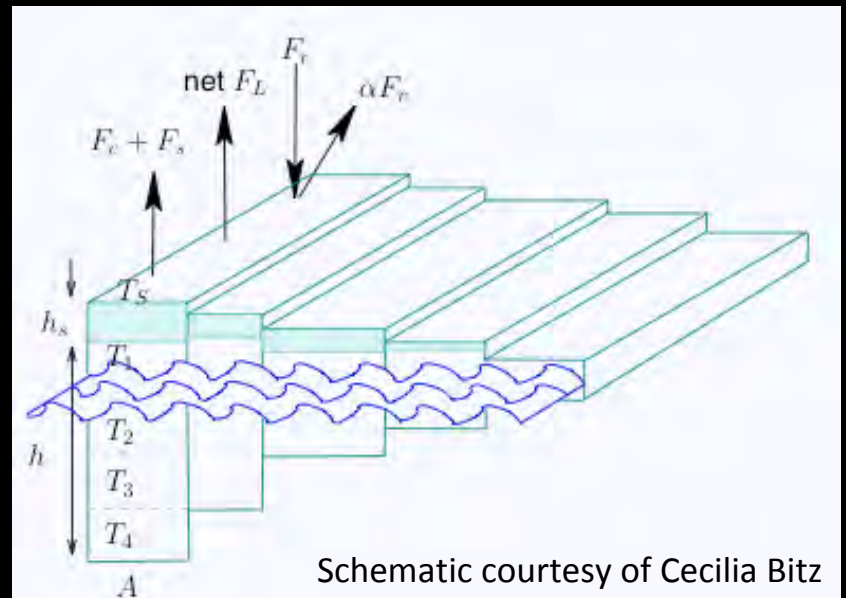
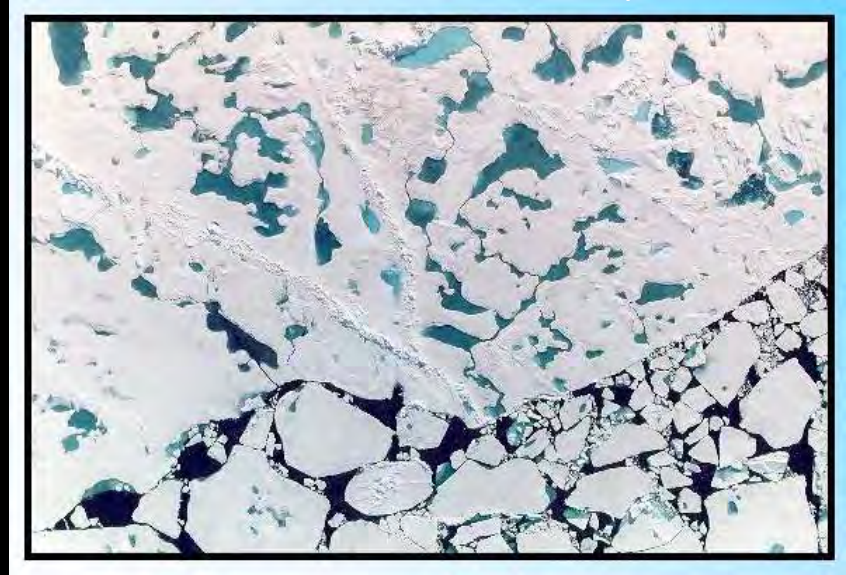
- Intrinsic climate variability
- Future greenhouse gas (and other external forcing) changes



# Sources of Uncertainty in Projections of Future Climate Change

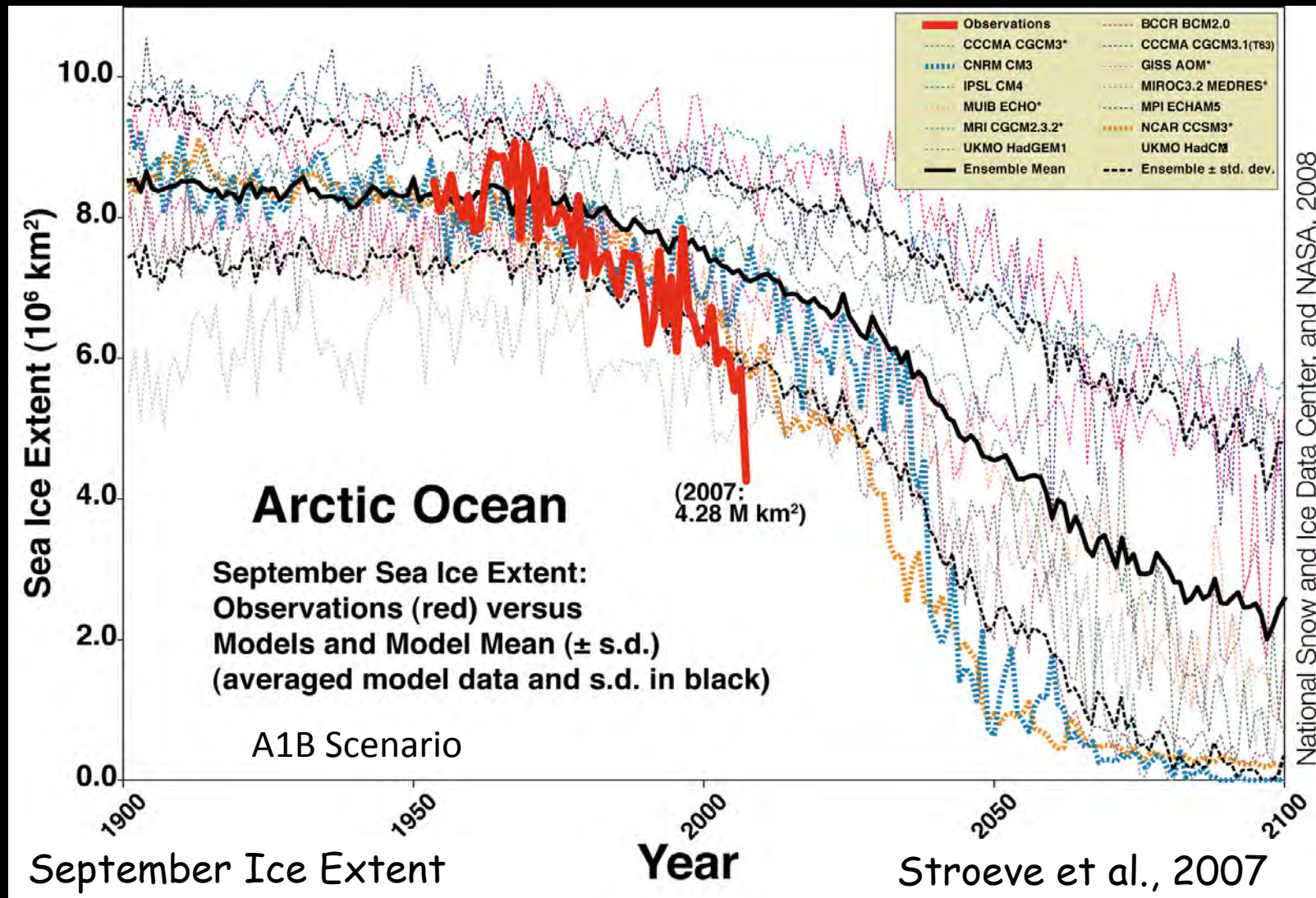
Photo courtesy of Don Perovich

- Intrinsic climate variability
- Future greenhouse gas (and other external forcing) changes
- Climate Model approximations



Schematic courtesy of Cecilia Bitz

# Model projections of September Arctic sea ice cover



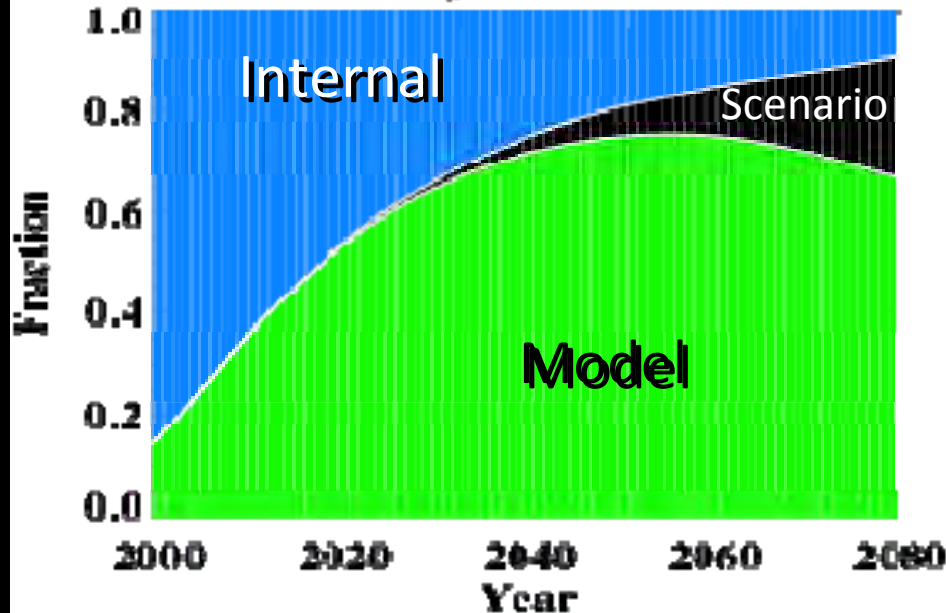
All models simulate ice loss  
Large range in magnitude of this loss  
Models simulate smaller trends than observations

# Sources of Uncertainty for Arctic ice change

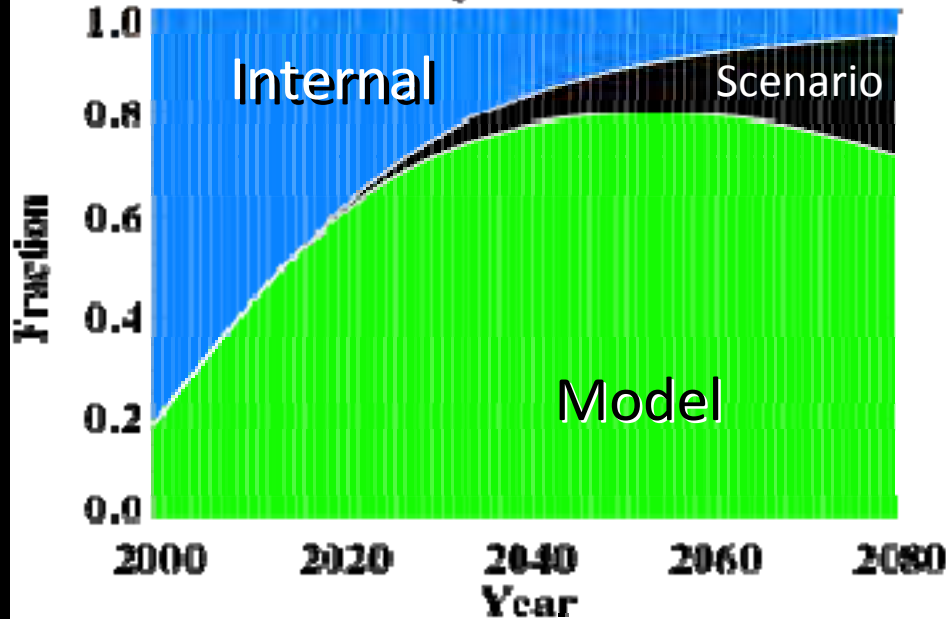
Using projections with different models & forcing scenarios, we can approximate the sources of uncertainty

- On <15 years intrinsic variability dominates
- On 20+ years, model uncertainty dominates
- On 50+ years, future GHG scenario uncertainty becomes important

**Uncertainty JFM Ice Extent**



**Uncertainty JAS Ice Extent**



# Reducing “Internal Uncertainty”

- Decadal climate prediction efforts underway.
- Involve initialized “forecasts”.
- Still very much a research problem.
- Have the potential to reduce the uncertainty associated with natural climate variations on 10-20 year timescales

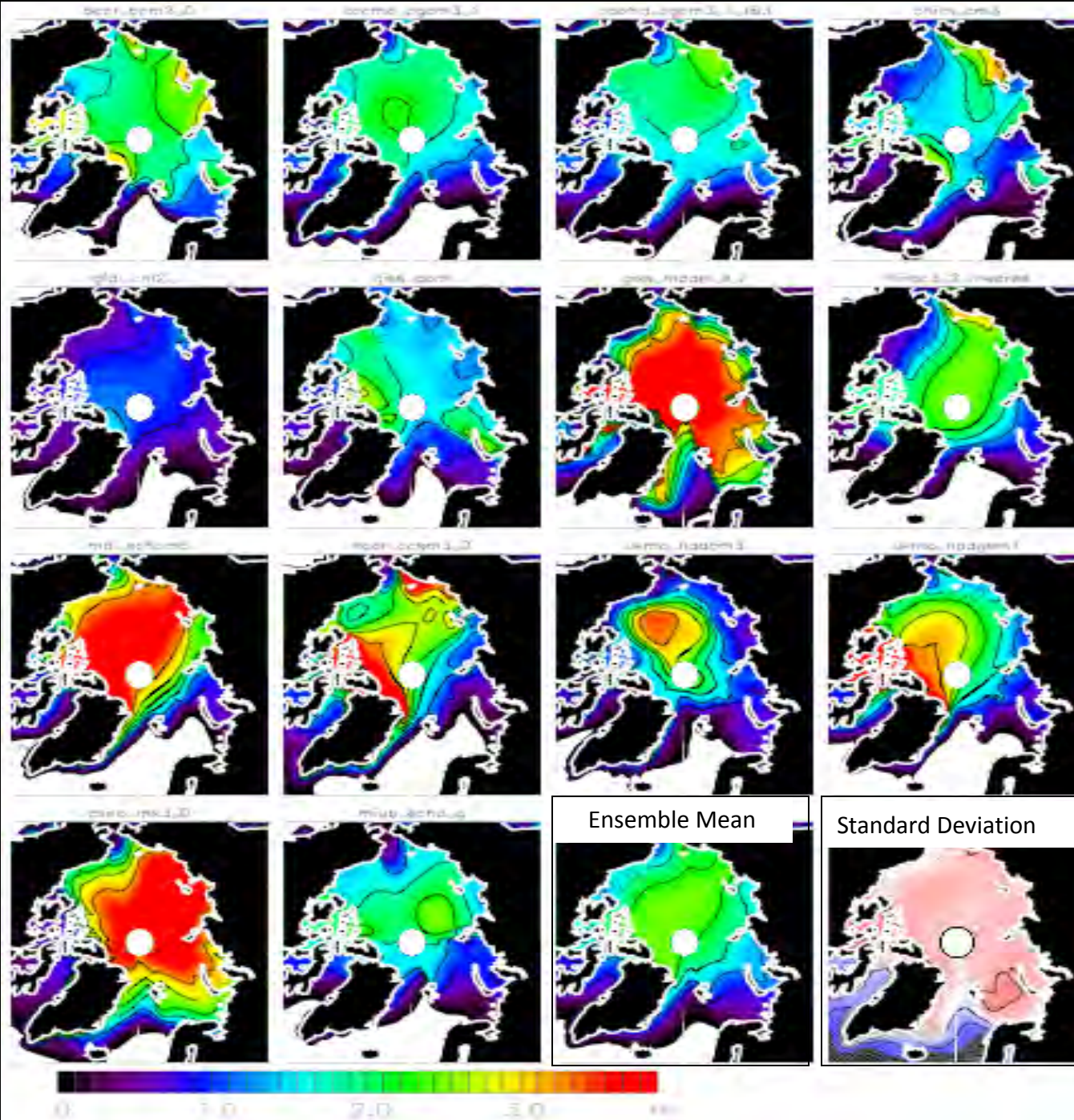
# Reducing "Model Uncertainty"

- Climate models are very complex systems
- Improvements and new capabilities are being incorporated continuously
- To reduce uncertainty for a particular model aspect, we need to understand what contributes to that uncertainty

What factors contribute to model uncertainty in future Arctic ice loss projections?

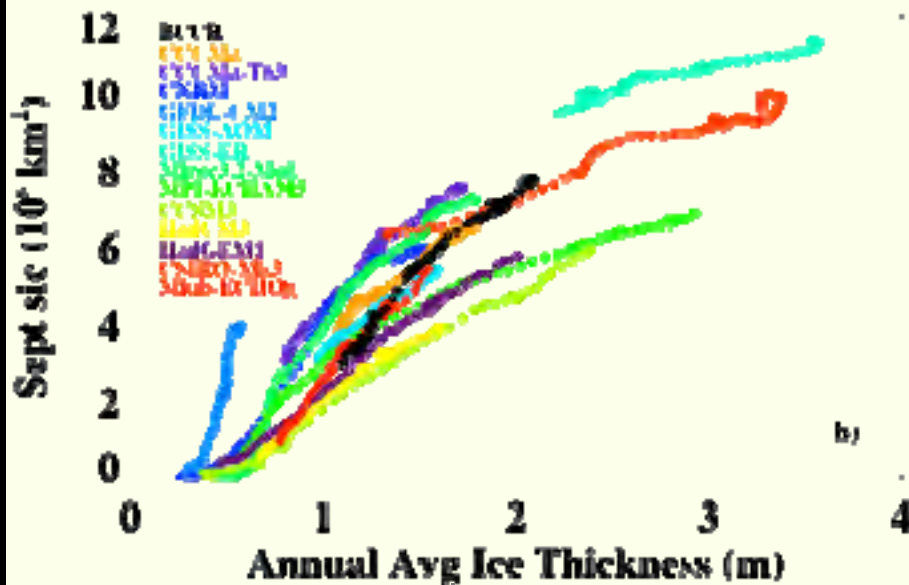
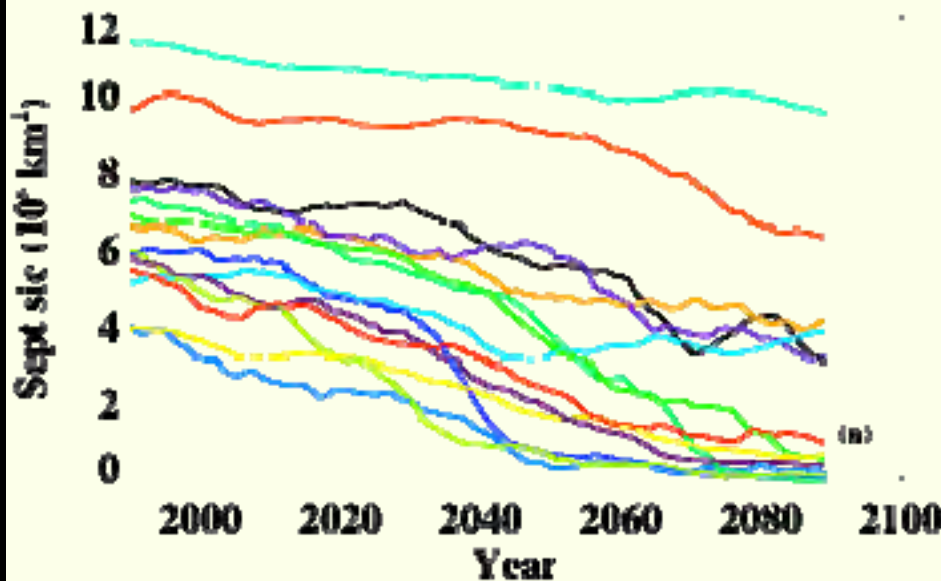
# Factors in "Model Uncertainty" of Projected Arctic ice loss

Initial Climate  
State



Ice Thickness  
Climatology  
from CMIP3  
Climate Models  
1980-1999

# Projected ice loss

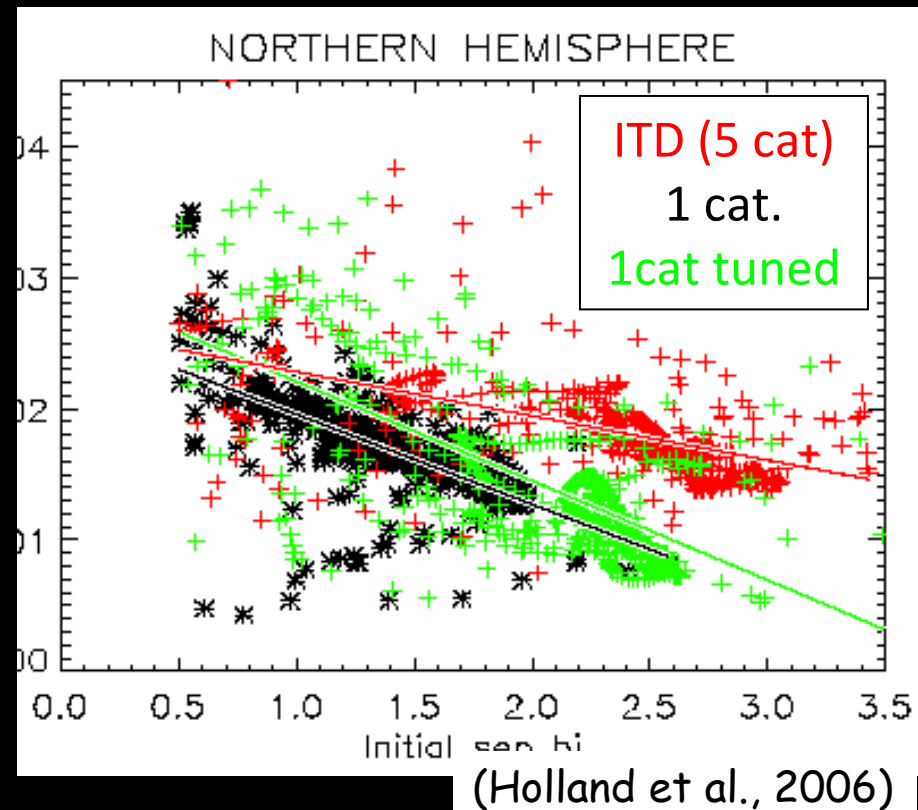
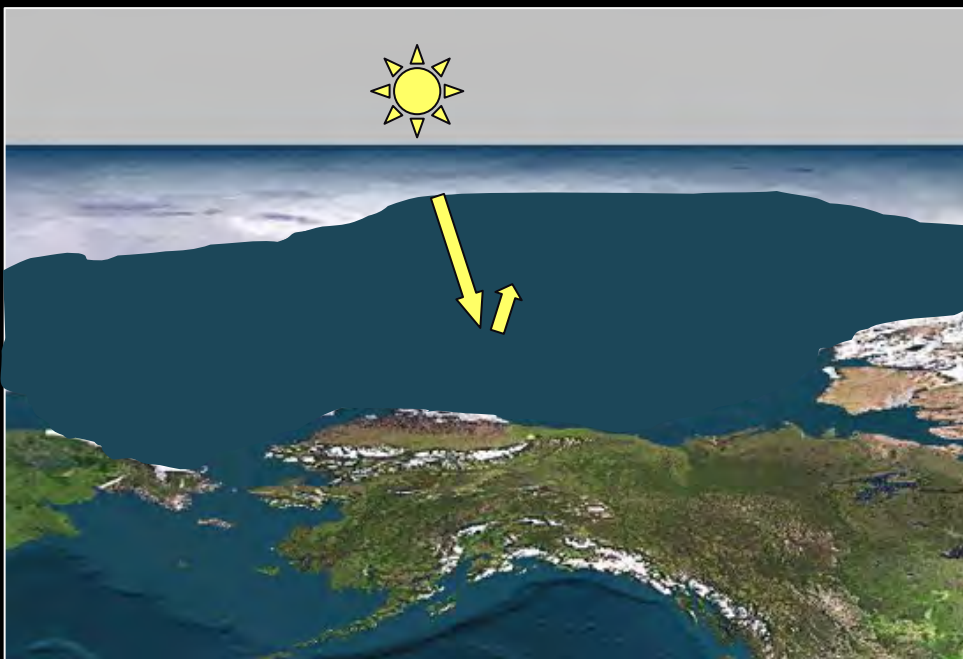
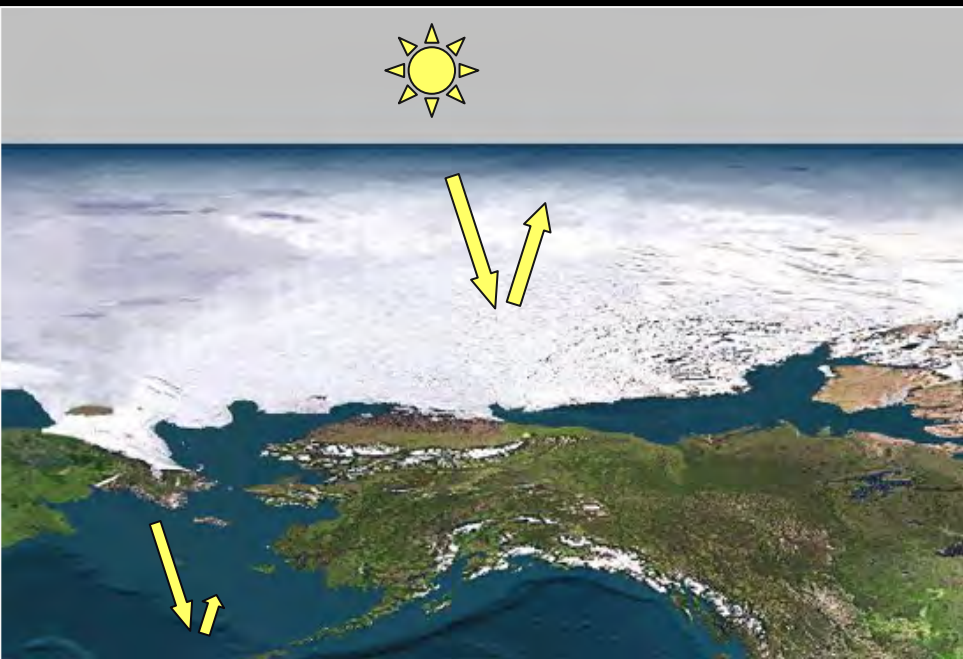


- Dependent on late 20<sup>th</sup> century conditions
- Models with thicker ice have larger ice volume loss but smaller ice area change
- In models with similar late 20<sup>th</sup> century ice thickness, spatial pattern of ice thickness matters
- Differences in albedo and cloud response are important for uncertainty in ice volume change

# Factors in "Model Uncertainty" of Projected Arctic ice loss

## Model Parameterizations

albedo feedback strength modified by inclusion of subgridscale ITD



# Factors in "Model Uncertainty" of Projected Arctic ice loss

## Missing (or Incomplete) Capabilities

Methane release from thawing permafrost

Soot deposition on snow and ice

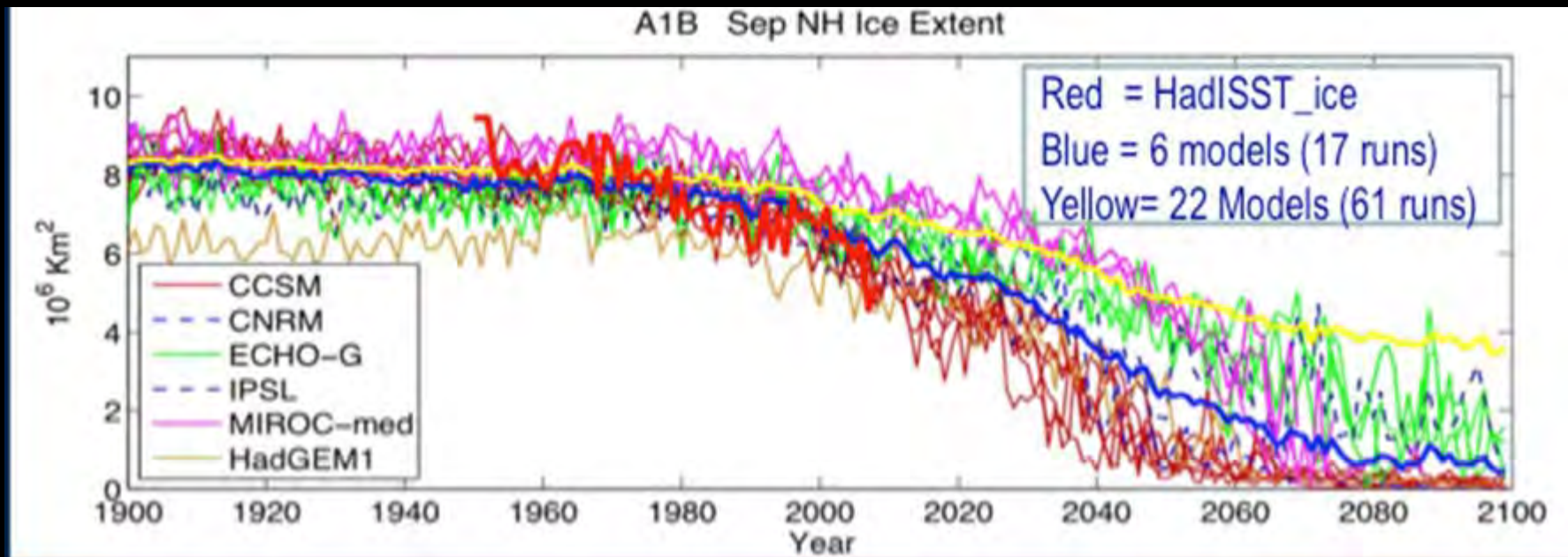
Aerosol effects on cloud formation

Ice sheet and glacier components

# Factors in "Model Uncertainty" of Projected Arctic ice loss

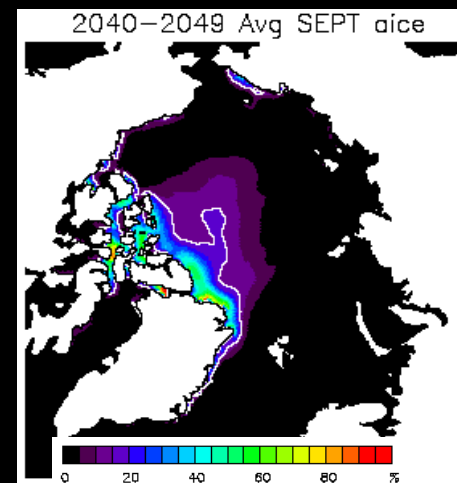
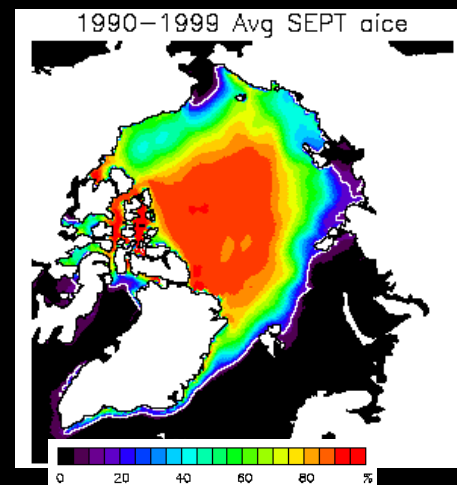
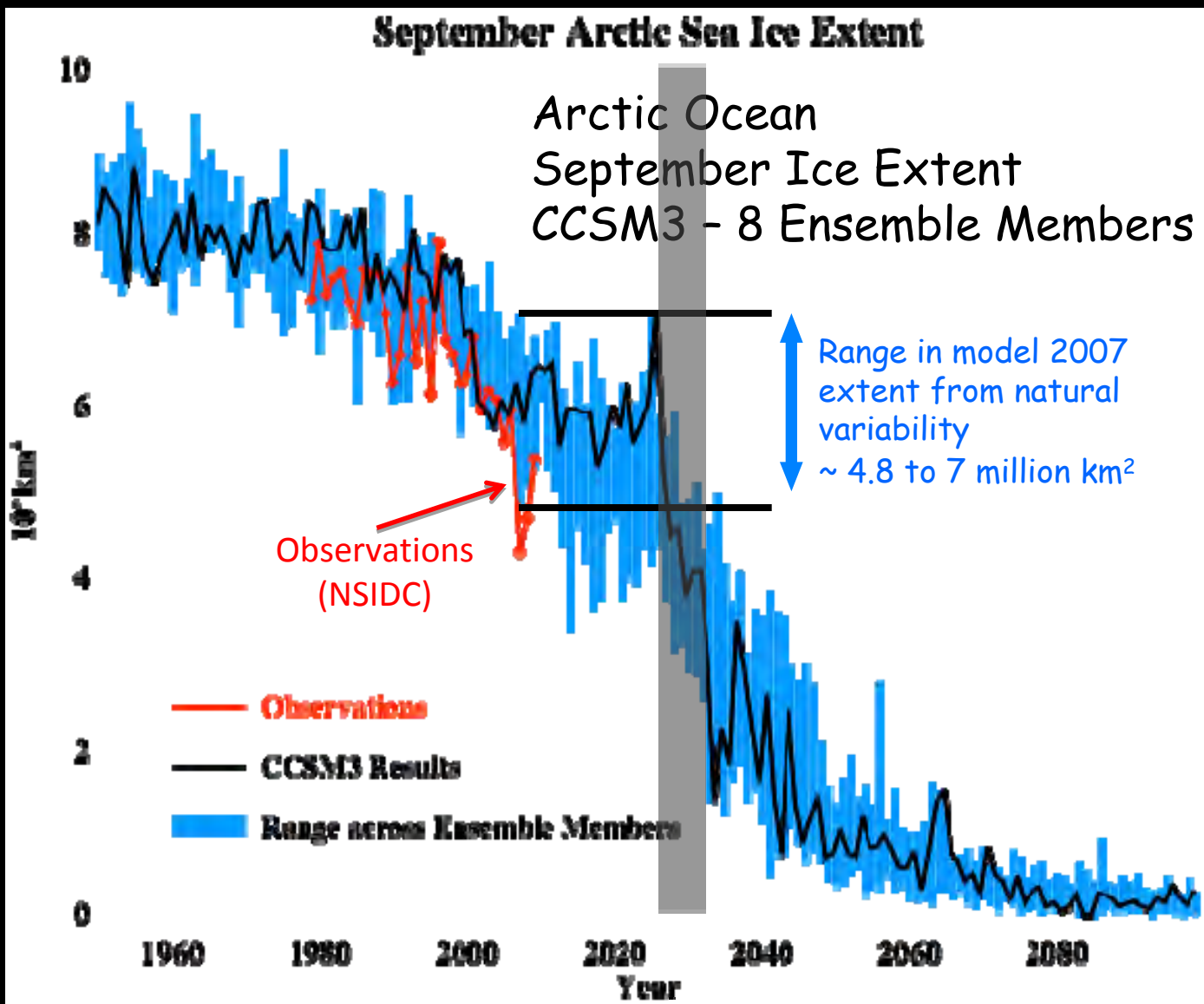
Suggest that more faith should be placed in projections from models with:

Well represented late 20<sup>th</sup> century Arctic sea ice  
More sophisticated physics and thermodynamics



(Wang and Overland, 2009)

# Potential abrupt loss of perennial sea ice



(Holland et al., 2006)

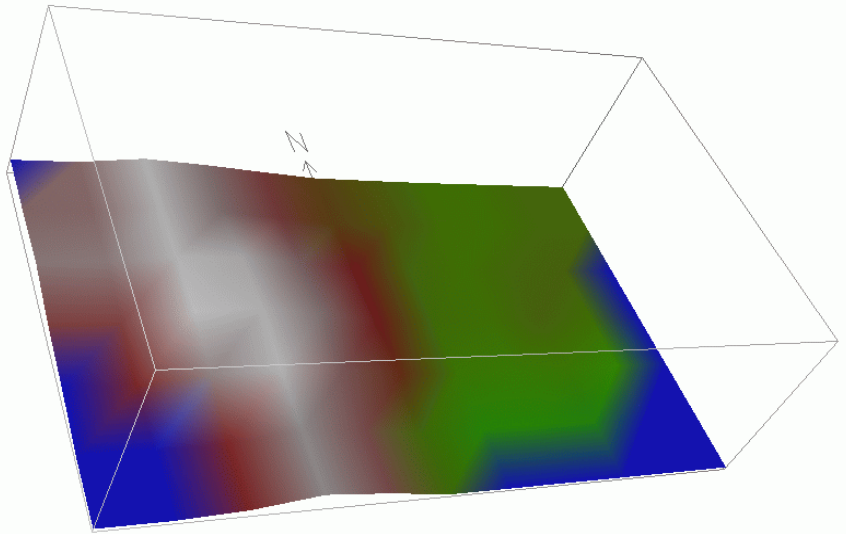
# Summary

- Future projections of Arctic sea ice loss are uncertain due to: intrinsic climate variability, forcing scenario uncertainty, model uncertainty
- Model uncertainty is influenced by simulated late 20<sup>th</sup> century conditions and the role of model representations on climate feedbacks
- Nevertheless, all models simulate enhanced Arctic warming and Arctic sea ice decline
- Faster rates of decline and a potential for abrupt changes in September sea ice are simulated by many of the better Arctic models

A polar bear is standing on a small, white ice floe in the middle of a blue sea. The bear is looking towards the camera. The water is a deep blue color, and there are other ice floes visible in the background.

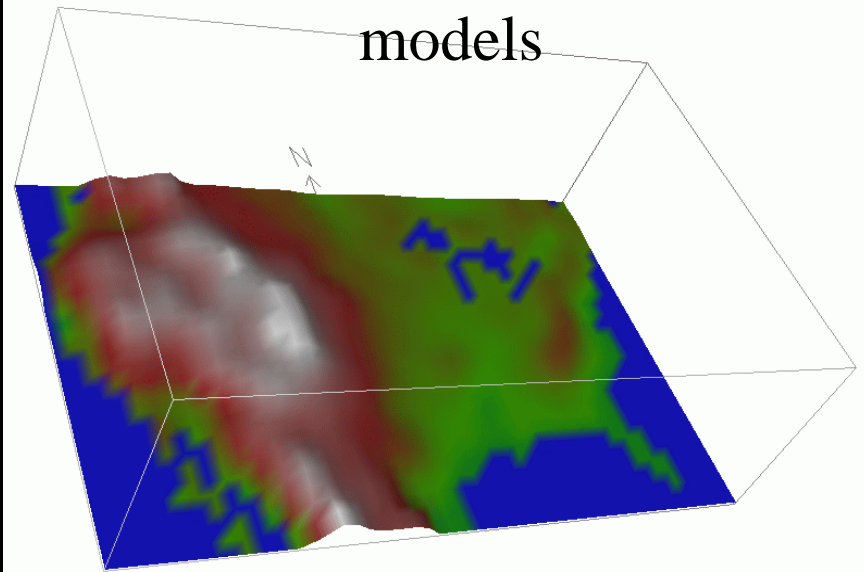
Questions?

Climate Models circa early 1990s



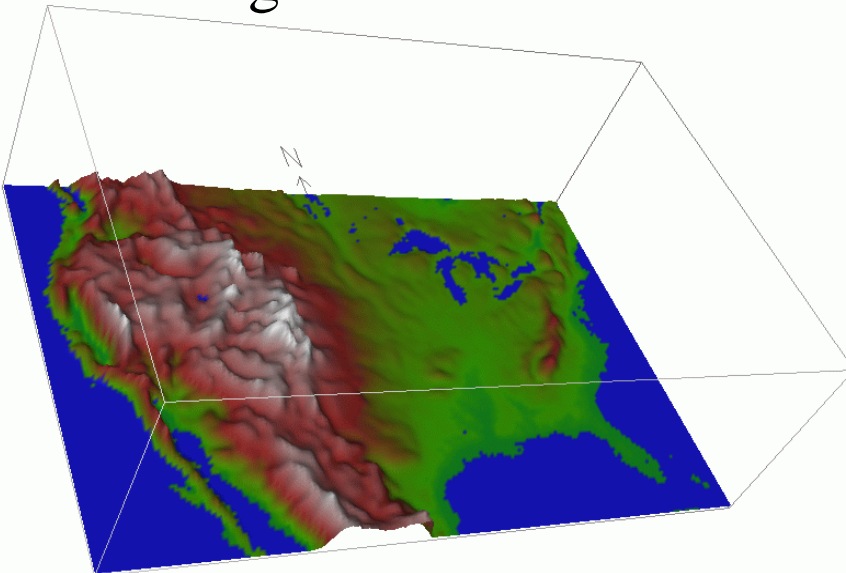
400 km

Current global coupled climate models



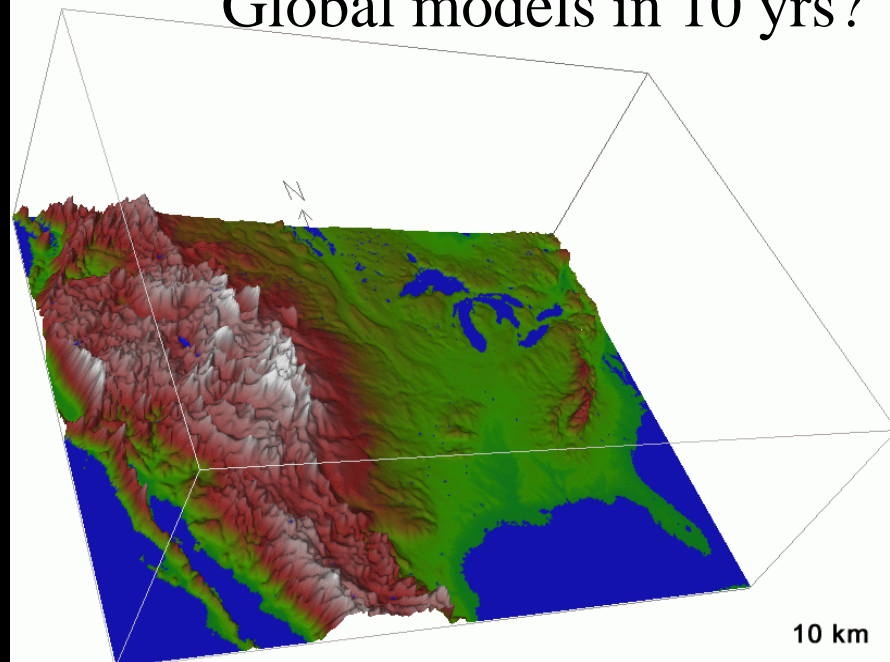
100 km

Regional models



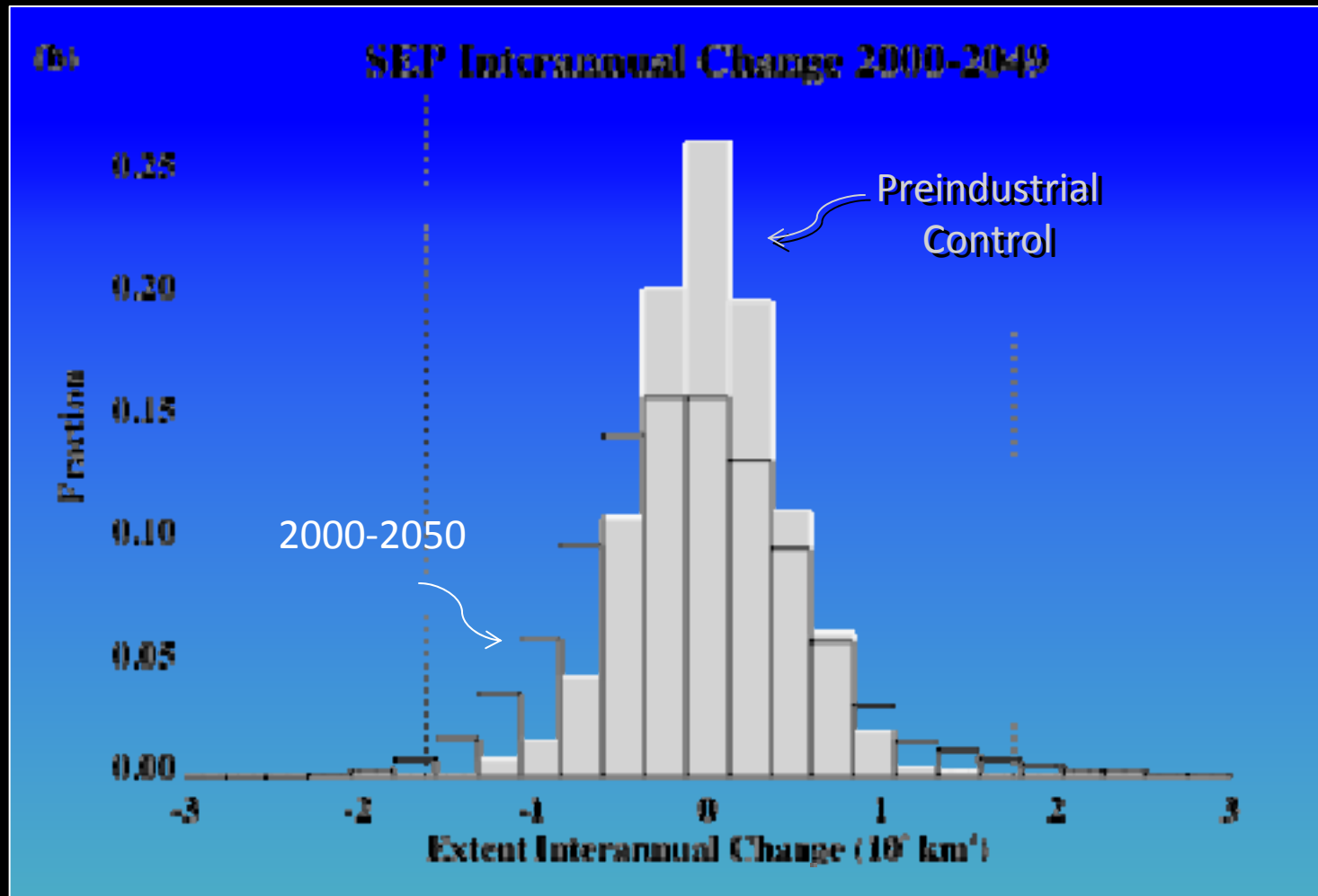
25 km

Global models in 10 yrs?



10 km

# Models indicate changing sea ice variability with changing climate state



(Holland et al., 2008)

Climate model projections: IPCC-AR4 models reach ice free Sept conditions between 2050 to after 2100.

